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CLASSIFICATION OF SAR SHIP IMAGES WITH THE AID OF A SYNTACTIC PATTERN RECOGNITION ALGORITHM

by

Robert Klepko

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

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CLASSIFICATION OF SAR SHIP IMAGES WITH THE AID OF A SYNTACTIC PATTERN RECOGNITION ALGORITHM

QUALITY INSPECTED 4

by

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ABSTRACT

Synthetic Aperture Radar (SAR) systems have made possible the generation of radar images of ships with high enough resolution to allow numerous targets or scatterers to be visible. With the availability of numerous scatterers in one radar image, it is theoretically possible to identify the class of a ship. The SAR image of a ship is a function of the location of scatterers, the SAR system frequency, the radar-to-ship viewing angle, the amount and type of sea-induced ship motion, and the length of the aperture. Because of the dependence on these variables, the number of images representing any one ship is large. It is the job of a Radar Operator to study and understand the abundance of radar images that can be encountered, and attempt to make the correct classification. Fast classification response times are required, however, since these images would normally be acquired in a real-time scenario. As a result of the large number of images and the fast classification response required, some form of computer-based aid for the operator is justified.

A Syntactic Pattern Recognition Algorithm (called the Coarse Feature Classifier (CFC)) has been developed to aid the Radar Operator in performing the task of classifying SAR images of ships. By having the algorithm perform some of the tasks that the operator normally performs, one obtains the potential benefits of improved accuracy and speed of classification, and reduced operator fatigue. The algorithm extracts numerous features from the input SAR image which are then compared to a library of similar features in order to select the ship(s) from the library which best resembles the input ship image. The extraction and comparison of features is a multi-step process.

The details of the operation of the CFC are discussed in this report. However, prior to this, the problem of SAR image classification is explained through the use of examples.

RÉSUMÉ

Les systèmes de Radar à Ouverture Synthétique (ROS) ont rendu possible la génération d'images de bateaux avec une résolution suffisamment grande pour rendre plusieurs cibles ou objets visibles. Il est théoriquement possible d'identifier la catégorie d'un bateau avec la quantité d'information disponible dans une seule image radar. L'image ROS d'un bateau dépend de la position de ses composantes, de la fréquence du système ROS, de l'angle du radar par rapport au bateau, de la quantité et du type de mouvement du bateau causés par la mer et de la grandeur d'ouverture. À cause de la dépendance par rapport à ces variables, le nombre d'images qui peuvent représenter un bateau donné est grand. C'est le travail d'un Opérateur Radar d'étudier et de comprendre les quantités d'images radars qui peuvent être rencontrées, et d'essayer de faire une classification appropriée. Cependant, les temps de réponse se doivent d'être rapides car ces images sont normalement obtenues lors d'un scénario en temps réel. À cause du grand nombre d'images et de la classification rapide de réponse exigée, la disponibilité d'une quelconque forme d'assistance par ordinateur pour l'opérateur est justifiée.

Un algorithme de reconnaissance de forme (appelé le Classificateur de Caractéristiques Générales (CCG)) a été développé pour aider l'Opérateur Radar à remplir la tâche de classifier les images ROS de bateaux. Grâce à l'algorithme, qui remplit quelques tâches qui sont normalement effectuées par l'opérateur, on obtient les améliorations potentielles de meilleure précision et vitesse de classification, et de réduction de la fatigue de l'opérateur. L'algorithme extrait plusieurs caractéristiques de l'image ROS qui sont alors comparées avec une collection d'images similaires afin de choisir le bateau qui ressemble le plus à l'image étudiée. L'extraction et la comparaison des caractéristiques est un processus à plusieurs étapes.

Les détails d'opération du CCG sont discutés dans ce rapport. Le problème de classification d'images ROS est d'abord discuté à l'aide d'exemples.

EXECUTIVE SUMMARY

Synthetic Aperture Radar (SAR) is used to generate high resolution radar images of targets and terrain. These radars are usually airborne or spaceborne, but in the application discussed here, the SAR is airborne and it is imaging targets as opposed to terrain. The targets are ships on the open ocean.

A SAR resolves a target in two dimensions. The first is the range dimension, which is along the line-of-sight of the radar. The second is the cross-range dimension, which is orthogonal to the line-of-sight of the radar and to the axis which the target is rotating about. Numerous scatterers on a ship are observable in the images generated by a SAR. It is the appearance and location of these scatterers which allows the ships in these images to be classified.

In a typical classification system, SAR images of ships are displayed on a monitor and viewed by a Radar Operator for the purpose of classifying the vessel in the image. Given a SAR operating at a single frequency and acquiring data over a fixed length aperture (these two constraints represent standard operating procedures), the appearance of a ship's SAR image is a function of the location of its scatterers, the radar-to-ship viewing angle, and the amount and type of sea-induced ship motion. Since there are many possible values assignable to these variables, there are certainly many different images which can represent the same ship, and since there are many different ships which can be imaged by the SAR, this magnifies the difficulty in classifying images. Furthermore, fast classification response times are expected since these images would normally be acquired in a real-time scenario. The large number of images that must be studied along with the speed at which a classification must be made are very demanding on the Radar Operator and justify the need for some computer-based aid.

A Syntactic Pattern Recognition algorithm, called the Coarse Feature Classifier, which aids the operator in classifying SAR images of ships, has been developed. By allowing the algorithm to perform some of the tedious tasks that the operator performs, improved accuracy and speed of classification should result. In addition, operator fatigue should be reduced since fewer tedious and redundant tasks are performed.

Within this report, a discussion of the SAR image generation process is given so that the reader may better appreciate the problems encountered in classification and understand why certain features are selected to classify an image. This is followed by a description of the operation of the Coarse Feature Classifier. This report concludes with a discussion on future work in this field of research.

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1.0 INTRODUCTION

Synthetic Aperture Radar (SAR) is used to generate high resolution radar images of targets and terrain. These radars are usually airborne or spaceborne, but in the application discussed here, the SAR is airborne and it is imaging targets as opposed to terrain. The targets are ships on the open ocean. These ships are imaged using a technique called Spotlight SAR (see Figure 1 [1]) where the narrow antenna beam of the radar tracks the target over some azimuth angle $\Delta\phi$. During the imaging interval, the SAR is flown in a straight line, the distance of which defines the length of the synthetic aperture.

A SAR resolves a target in two dimensions. The first is the range dimension, which is along the line-of-sight of the radar. The second is the cross-range dimension, which is orthogonal to the line-of-sight of the radar and to the axis which the target is rotating about. Note that the straight line (tangential) motion of the SAR results in an axis of rotation about the target. Since the targets are ships at sea, they will experience some additional rotational motion induced by sea motion. The various motions induced on a ship while at sea are depicted in Figure 2. Resolution in the range dimension is inversely proportional to the bandwidth of the radar or directly proportional to the transmitted radar pulse width. Resolution in the cross-range dimension is inversely proportional to the azimuth angle $\Delta\phi$ and directly proportional to the wavelength of the transmitted radar signal, but it also affected in a complex way by the sea-induced ship motion. High resolution in cross-range is achieved with a high frequency radar and a constant rate of rotation over a large angle. The rotation rate can be induced by either the ship's or radar's motion. If it is caused by the ship's motion, steps must be taken to ensure the effective rotation is constant. Under suitable conditions of ship motion, typical range and cross-range resolutions are a few meters or less. Formulas for computing these resolutions can be found on page 216 of [1].

Numerous scatterers on a ship are observable in the images generated by a SAR. It is the appearance and location of these scatterers which allows the ships in these images to be identified according to their class. The types of scatterers range from points to plates to corner cubes. The appearance of these scatterers in a SAR image can grossly be described as a two-dimensional topology of a few high-level peaks, plus numerous low-level peaks. Figure 3 is a typical SAR image of a tanker. The image was generated by an airborne SAR system called the SAR580. This system, which has since been dismantled, was owned and operated by the Canada Centre for Remote Sensing. The image shown is 256 by 256 pixels, with a range and cross-range resolution of 2 meters. There are approximately one dozen high-level peaks and at least three times as many low-level peaks. As will be discussed in the following section, with small changes in ship orientation, the location and absolute height of low-level peaks tend to vary rapidly, while the location and absolute height of high-level peaks vary only slightly. For this reason, only the high-level peaks are consistent and therefore reliable enough to use for classifying a ship image.

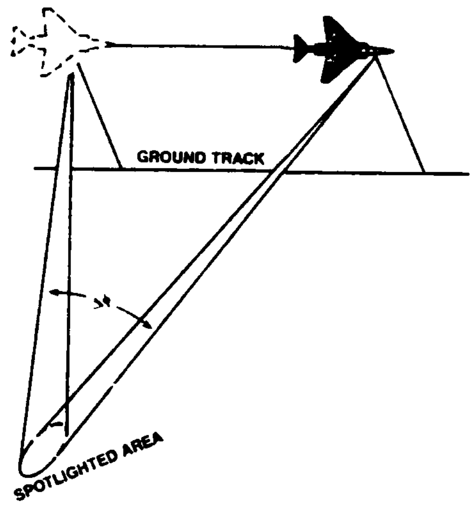


Figure 1 Spotlight SAR [1].

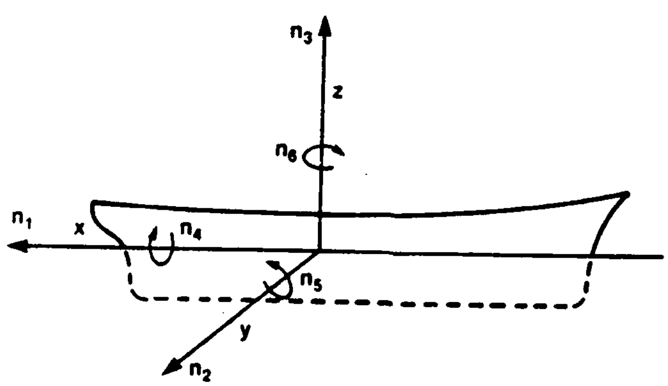
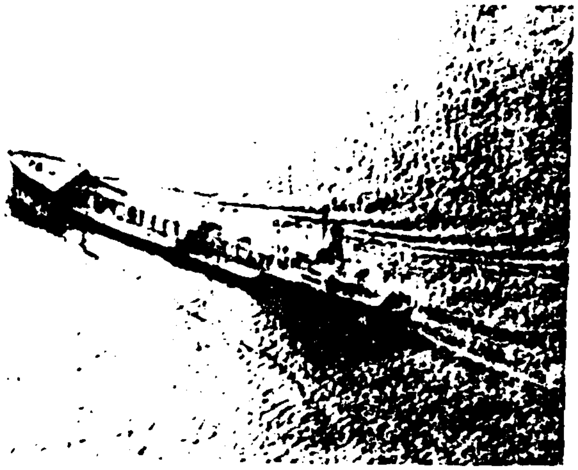
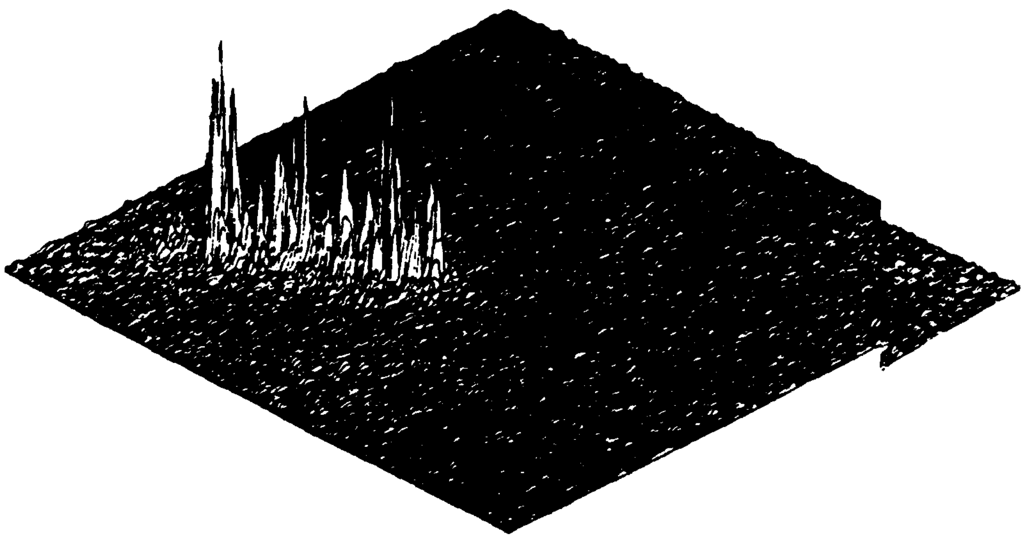


Figure 2 The six types of ship motion (n_1 = surge, n_2 = sway, n_3 = heave, n_4 = roll, n_5 = pitch, n_6 = yaw).



(A)



(B)

Figure 3 (A) Photograph of a tanker ship at sea, and (B) its corresponding SAR image.

In a typical classification system, SAR images of ships are displayed on a monitor and viewed by a Radar Operator with the purpose of identifying the class of vessel in the image. Given a SAR operating at a single frequency and acquiring data over a fixed length aperture (these two constraints represent standard operating procedures), the appearance of a ship's SAR image is a function of the location of its scatterers, the radar-to-ship viewing angle, and the amount and type of sea-induced ship motion. The viewing angle includes the aspect angle, which is the angle between the radar line-of-sight and ship heading, and the depression angle, which is the angle between the ocean surface and radar line-of-sight. Since there are many possible values assignable to these variables, there are certainly many different images which can represent the same ship. There are also many different ships that can be imaged by the SAR, which further magnifies the difficulty in classifying the images. Furthermore, fast classification response times are needed since these images would normally be acquired in a real-time scenario. The large number of images that must be studied, along with the speed at which a classification must be made, are very demanding on the Radar Operator and justify the need for some computer-based aid.

A Syntactic Pattern Recognition algorithm, called the Coarse Feature Classifier, has been developed to aid the operator in classifying SAR images of ships. By allowing the algorithm to perform some of the tedious tasks that the operator performs, improved accuracy and speed of classification should result. In addition, operator fatigue should be reduced since fewer tedious and redundant tasks are performed. The algorithm preprocesses the SAR images to enhance certain coarse features contained in them. These features are termed coarse since they can be found in all the ship images, nevertheless, the value assigned to these features is usually different for different images. Every ship is represented by a particular combination or syntax of feature values, hence the use of the name Syntactic Classifier. A different set of feature values is assigned for every possible ship orientation. Since there is some similarity in the feature values assigned to different ships, there is some potential for confusion as to the true class of the ship. Working with an initial library of about 100 ships, the goal of the classifier is to reduce this library down to less than 10 candidate ships. These candidate ships are then analyzed in more detail by the operator to try and reduce this list down to one class of ship.

In the following section, a discussion of the SAR image generation process is given so that the reader may better appreciate the problems encountered in classification and understand why certain features are selected to classify an image. This section is followed by a description of the operation of the Coarse Feature Classifier. The final section of this report will discuss future work in this field of research.

2.0 SAR IMAGE GENERATION

2.1 Image Generation Process

SAR systems are capable of generating images with high resolution in both the range and cross-range dimensions. The resolution in the range direction is obtained by coding the transmitted radar pulse, typically using a linear frequency-modulated (LFM) or chirp coded signal (see Section 4.6 of [1]). Figure 4 illustrates such a signal [1], which has its center frequency typically set to the operating frequency of the radar (e.g. 10 GHz). SAR image generation in the range dimension is achieved with pulse-compression (e.g. matched filtering) which compresses the LFM signal reflected from each scatterer into a sinc function. The width of this sinc function at the -3 dB level is approximately equal to the reciprocal of the bandwidth of the transmitted radar signal. The location of the sinc function in the range dimension is a function of the transmit-to-receive delay of the reflected radar signal. This delay is a function of the distance of the scatterer to the SAR.

Resolution in the cross-range dimension is also made possible through the reception and processing of LFM signals, where the LFM signal is seen in the sequence of reflected radar pulses and not within a pulse. Figure 5 shows a typical scenario for a Spotlight SAR imaging a ship on the surface of the ocean. The ship is a distance R_i from the SAR. The SAR is at a height H (not shown) above the ocean surface. The SAR is flying in a straight line with a velocity V_p. Highlighted on the ship are three point scatterers which, for this example, are assumed to be the only scatterers visible to the SAR. Scatterers A and C are assumed to be at deck level, while scatterer B is located near the top of the ship's superstructure, but at the center of the length of the ship. As the SAR flies from position Z_1 to Z_2, it transmits and receives a number of radar pulses (which can be LFM coded) at a certain pulse-repetition-frequency (PRF). Since the SAR is moving relative to the scatterers, for each scatterer i, there is a radial, $V_{R(i)}$, and cross-radial, $V_{CR(i)}$, velocity component resulting from the linear velocity, V_p, of the SAR. Only the velocity components for scatterer A are depicted in the figure. The direction and magnitude of each component changes as the SAR flies by the scatterers. It is the radial component of velocity which causes there to be a Doppler frequency shift in the reflected radar pulses: $f_{DOPPLER} = 2V_{R(i)}{}^{*}\cos\Psi/\lambda$, where λ is the wavelength of the radar and Ψ is the angle between the radar line-of-sight and the SAR velocity vector, as shown in Figure 5. For a stationary ship, the Doppler frequency history of the three scatterers would typically appear as illustrated in Figure 6(a). The relative frequency of the scatterers at any point in time is a function of their relative cross-range locations. The slope of each Doppler frequency history is approximately the same. This received signal resembles the LFM signal transmitted by the SAR, which is used to generate the range resolution. Recall that the range signal is compressed with a matched filter to resolve targets in the range direction. Hence, a similar form of compression can be applied to the series of radar pulses reflected by a scatterer to resolve scatterers in the cross-range direction. After compression in both directions, a point scatterer is produced at the appropriate cross-range and range location in the SAR image.

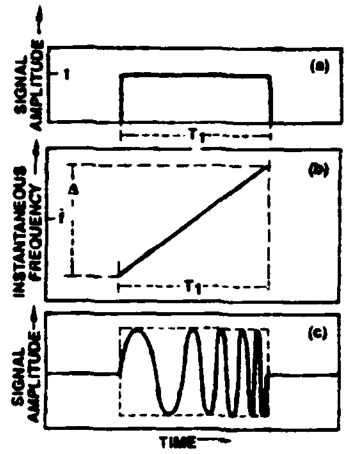


Figure 4 Linear frequency-modulated transmitted radar signal [1].

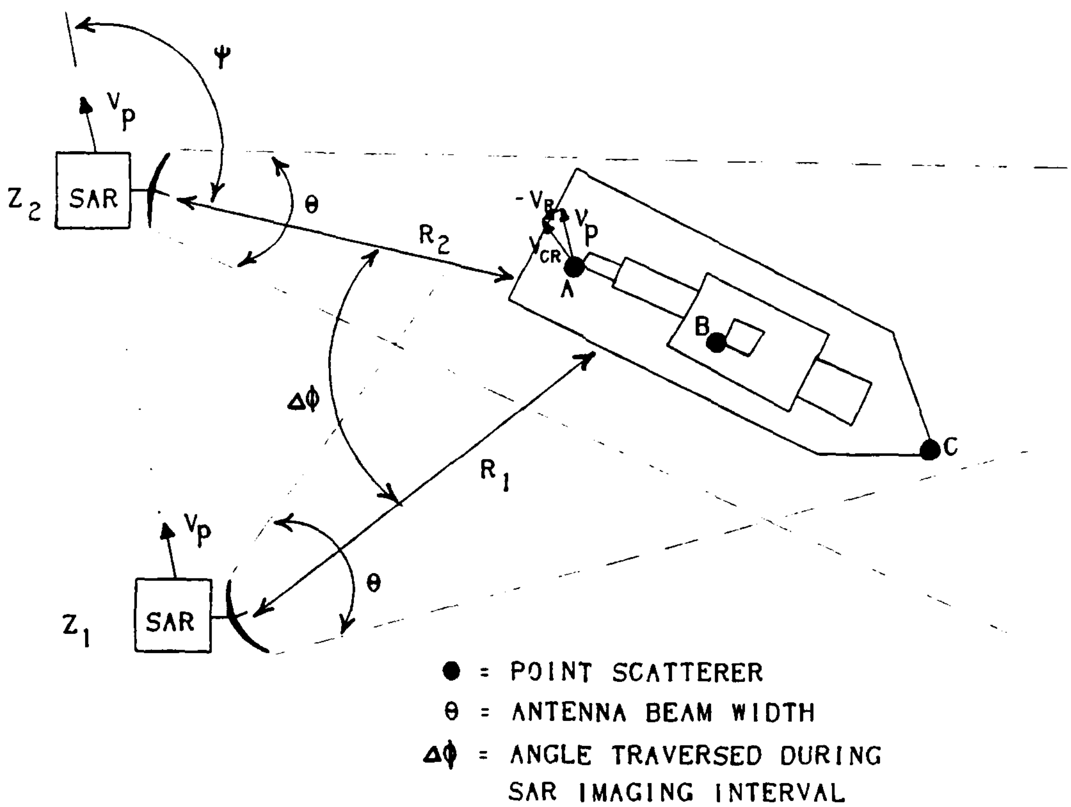


Figure 5 Typical Spotlight SAR operating scenario (top view).

In the real world, however, the ship is usually moving in a forward direction under its own power, and has sea-induced motion, as illustrated in Figure 2. As a result of these motions, the Doppler frequency history of each target would not be a straight line, and each target would have different time-varying slopes. This is illustrated in Figure 6(b). When the signal history of each of these scatterers is compressed, the image of the scatterer will not be represented by a single point, but will be defocussed. This means that each scatterer's reflected energy will be smeared or spread over several cross-range image pixels. To focus this energy into one image pixel some form of autofocussing technique must be employed.

Conceptually, what the autofocussing technique must do is cancel the average slope of the Doppler frequency history of each individual scatterer. Next, if the slope is not straight over the observation period over which it is viewed, then it must be straightened. These two processing steps are illustrated in Figure 7. Finally, a Discrete Fourier Transform (DFT) of this signal is taken, and the location of the point scatterer's signal in the spectral domain determines its location in the final SAR image. The ultimate resolution (measured in Hz) achievable in the cross-range dimension is determined by the frequency resolution of the DFT. This resolution is computed by dividing the PRF by the number of points used in the DFT. The points used represent a segment of data from the input data sequence. If there are not any complications because of the ship's motion, or our ability to compensate for (or ignore) its effect, then the more points, or reflected radar pulses, used in the DFT (i.e. the longer the synthetic aperture), the finer is the resolution.

Note that both the range and cross-range signals are linear FM in the Spotlight SAR configuration. However, the cross-range signals are *completely overlapped in time*, but offset in frequency, whereas the range signals are completely overlapped in frequency, but offset in time. This necessitates the use of different compression techniques for range and cross-range, that is matched filtering versus DFT, respectively.

2.2 Image Scaling Problem

Although the idealized autofocussing technique focusses targets in the final image, there is an inherent scaling problem resulting from the fact that frequency, and not distance, is used as a measure of resolution in the cross-range dimension. The scaling problem results from the unknown and time-varying orientation of the velocity vector for each scatterer, as analyzed in [2]. Several orientations can give rise to the same relative radial velocity components. Since the cross-range linear FM rate is the link between distance and frequency, and the FM rate depends on the velocity vector, whose orientation is unknown, it is difficult to determine the scale. A couple of examples help to illustrate this problem. It can be seen from Figure 6(b) that the Doppler frequencies at which the scatterers are resolved depend on the start time of the data segment used in the autofocussing process. It is the Doppler frequency of a scatterer at the beginning of the data segment which defines the frequency of the scatterer's signal after it has been deramped and focussed. For

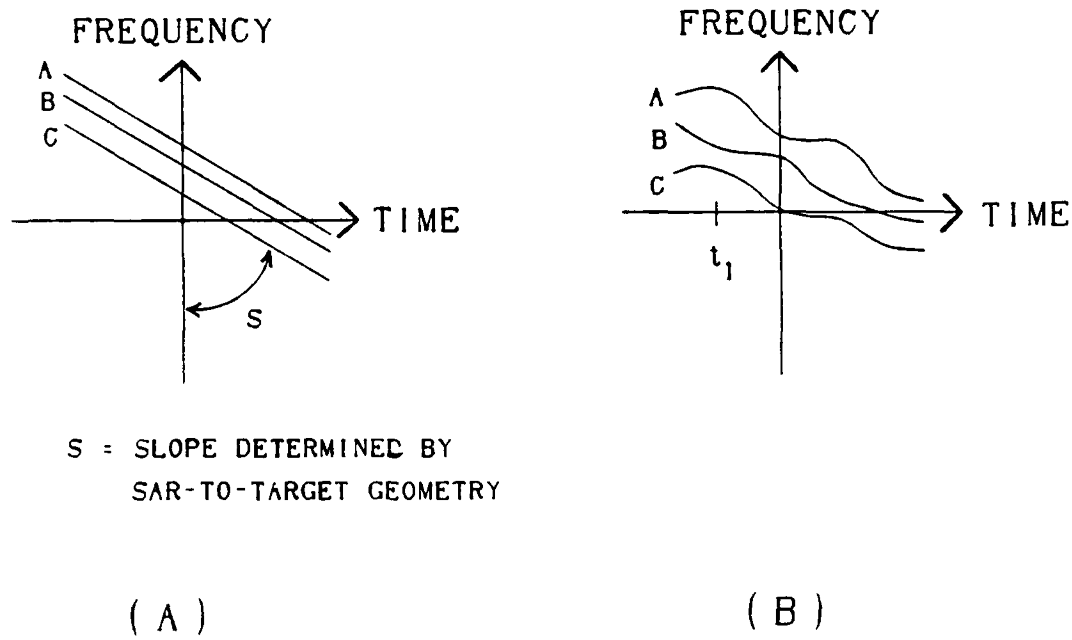


Figure 6 Doppler frequency history of the three scatterers on-board the target ship for (A) no ship motion, and (B) ship motion.

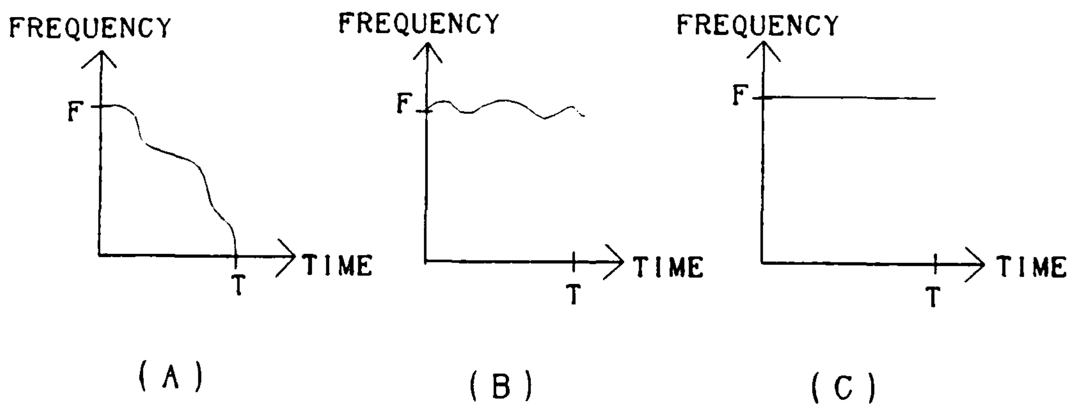


Figure 7 Autofocussing of an individual scatterer with (A) Doppler history of a point target, (B) slope removed from data, and (C) focussed data.

instance, if the start time is selected to be t_1, then the Doppler frequency difference between scatterers B and C is less than that between scatterers A and B. At time $t = 0$, however, the Doppler frequency difference between scatterers A and B is less than that between scatterers B and C. If the ship were stationary (i.e. Doppler histories as shown in Figure 6(a)), then the displacement of the scatterers in the cross-range direction would be the same as they appear on the ship, as shown in Figure 8(a). For example, if the ship is yawing, then the motion of scatterers A and C induces additional Doppler frequencies on their reflected radar signals, but the Doppler frequency history of scatterer B does not change since it is located at the axis of rotation. If the bow of the ship is moving away from the SAR and the stern is moving towards the SAR during the imaging interval, then the Doppler frequencies of scatterers A and C become more positive and more negative, respectively. The resulting image would appear as in Figure 8(b). Observe that the range locations of the scatterers are preserved when compared to Figure 8(a), but the apparent cross-range length of the ship is now stretched. If the bow of the ship is moving towards the SAR, then the effects on the Doppler frequencies of scatterers A and C are reversed and the image of Figure 8(c) results. Note that even though the physical locations of the scatterers have not changed, their image locations have. Thus, the image has been scaled, where the amount of scaling is directly dependent on the amount and type of ship motion. If the motion of the ship or its orientation were known, then the scale could be estimated. However, in general, the motion is too complicated and ship orientation is not known, so the scaling factor remains unknown.

As another example of the effects of ship motion on final image appearance, assume that the ship is rolling. Since scatterers A and C are located on the deck of the ship, they are not affected by this motion (approximately speaking), but the Doppler frequency history of scatterer B is affected since it is located well above the deck. If the ship is rolling towards the SAR, then the Doppler history of scatterer B would become more positive and the image in Figure 8 (d) would result. The image in Figure 8(e) results for a ship rolling away from the SAR. Again, these two images demonstrate the image scaling problem.

The sequence of images in Figure 8 demonstrates that, for any given ship with a fixed orientation between the radar line-of-sight and ship heading, there are many SAR images that can be produced for the same ship as it undergoes its sea-induced motion. Examples of such (simulated) images are given in [2]. Also, note that it is possible that different ship structures, with different amounts of motion, can produce similar images. Since there are a variety of combinations of ship motion and a large number of ships that can be imaged, an enormous number of SAR images can be generated, and there exists the possibility of some overlap in the appearance of these images. Thus, the task of identifying the class of a ship in a SAR image is made difficult and justifies the need for some computer-based aid for the Radar Operator.

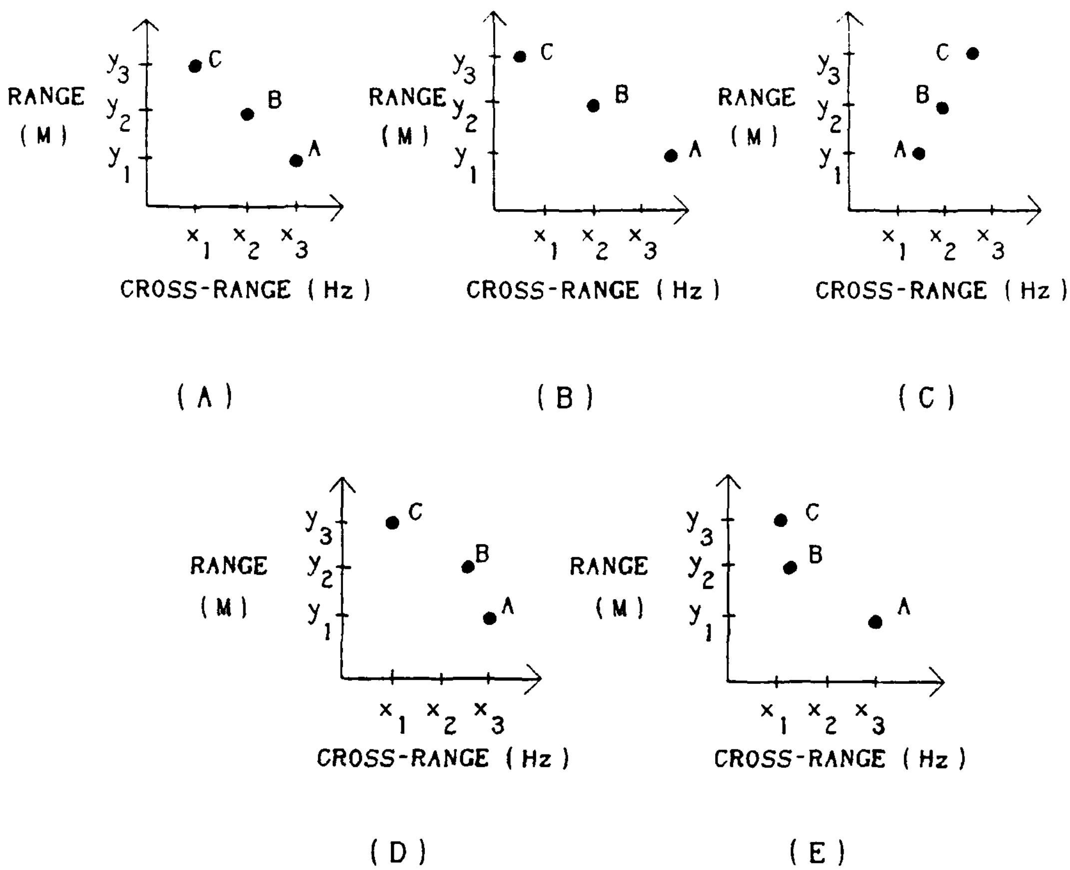


Figure 8 Idealized SAR images (top or contour view) of the ship in Figure 5 used to illustrate the image scaling problem for a fixed ship orientation. (A) No ship motion. (B) SAR image resulting from yaw motion with bow of ship moving away from the SAR. (C) SAR image resulting from yaw motion with bow of ship moving towards the SAR. (D) SAR image with ship rolling towards the SAR. (E) SAR image with ship rolling away from the SAR.

3.0 SHIP IMAGE CLASSIFICATION

3.1 Introduction

To aid the Radar Operator in classifying SAR images of ships, a Syntactic Pattern Recognition algorithm has been developed. This type of algorithm utilizes a combination of various image features whose assigned values define a certain ship, at a certain orientation. The features selected can be found in all SAR images, so they are termed coarse. Since coarse image features are used, the algorithm is called the Coarse Feature Classifier (CFC). If features specific to one ship are found, they are used since this represents a unique footprint for that ship. An example of a unique feature is discussed in the following subsection. The image features selected and the operation of the CFC are also topics of the following two subsections.

3.2 Image Feature Selection

To ensure reliability, the image features selected for classifying SAR images must be consistent. From the sequence of images presented in Figure 8, the cross-range location of a scatterer would not be a consistent feature since it varies through time as the result of inconsistent sea motion. Fortunately, the range location of a scatterer is more consistent. This consistency is true even over a range of both aspect and depression angles. This range of angles is dependent upon the range resolution in the SAR image.

In defining the range of angles, it has been assumed that only the high level peaks in a SAR image are used as features and that the low level peaks have been thresholded out. The high level peaks include the highest level peak and all peaks whose amplitude is within 1/30th of the amplitude of the highest level peak. In our simulations, it has been found that the low level peaks tend to vary in both height and location with only small changes in the aspect and depression angles, while the high level peaks do not. One way to obtain a set of consistent image features of a SAR image of a ship is to first threshold it to remove the low level scatterers, and then collapse (i.e. incoherently sum) the image that remains along the cross-range dimension. This is done in each range resolution cell with the result that a range profile of the image is generated. It is called a range profile since the image represents the distribution of radar reflected energy in the range dimension only. The range profile is then normalized by dividing each pixel in the profile by the square root of the sum of the squares of the pixel amplitudes. Figure 9(a) shows a (simulated) SAR image of a ship. Its corresponding range profile is shown in Figure 9(b).

Once the original SAR image has been preprocessed to generate a more consistent image in the form of a range profile, the image features can be extracted. The features include: the number, level and location of peaks; and the range extent of the image (i.e. the number of range resolution cells occupied by a ship in the image). Each of these features

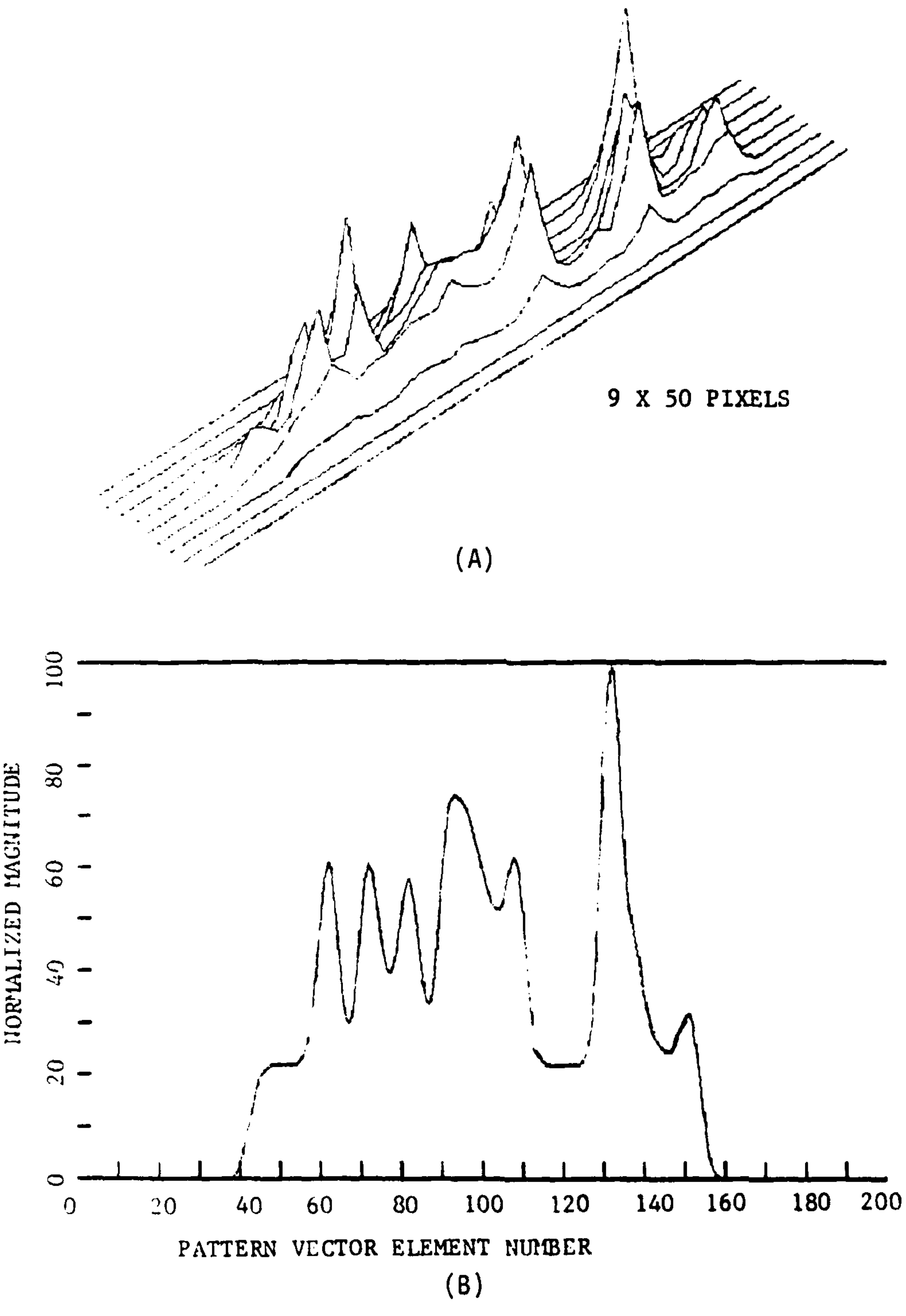


Figure 9 (A) Simulated SAR image of a ship, and (B) range profile of the same image.

can be found in any range profile of a ship. The value assigned to these features depends upon the ship being imaged and the aspect and depression angles.

An additional image feature that is present in only some SAR ship images is a rotating antenna, as suggested in [3]. A rotating antenna appears as a streak of energy along the cross-range dimension of a SAR image. No other type of ship scatterer can produce such an image feature, so when a streak is found it is known to be an antenna. The range location of the antenna can be extracted and used as a classification feature. Note that if the antenna is not rotating, then it does not appear as a streak in an image, but likely as a peak whose level depends upon the viewing angle of the antenna by the radar. Also, by tracking, in range, the main scatterer on the ship using the radar data, it is possible to determine the bow and stern of a ship in the SAR image.

One further image feature that can be used is an estimate of the aspect angle between the ship heading and the radar line-of-sight. The estimation procedure is beyond the scope of this report. This estimated angle can be used to define the center of a range of angles since an exact angle is impossible to compute. This range of angles coupled with the range extent is used to generate bounds on the possible length of a ship in an image. This thereby alleviates the scaling problem discussed in subsection 2.2.

3.3 Coarse Feature Classifier Operation

The Coarse Feature Classifier (CFC) has two basic functions. The first is to create a library containing sets of feature values, with one set corresponding to one class of ship at a particular viewing angle. This library is created offline, prior to the execution of the classification process. The second function is to preprocess an input SAR image of a ship, extract values for the set of features, and compare this set of values to the sets stored in the library to determine which ship class(es) give the best match. Each function is described in more detail below.

3.3.1 Image Feature Library Creation

To acquire the SAR images of each class of ship, in their various orientations, using a real SAR system would be very costly, time consuming and difficult. Instead, these images are simulated [4], an example of which is shown in Figure 9. This involves the computer simulation of the data acquisition function of the SAR system, the estimation of scatterer radar cross sections, the creation and utilization of computer-based ship models to define the location of (major) scatterers, and the implementation of the SAR system image generation functions. The simulation process is both cost effective and relatively fast.

Using the simulated SAR images, range profiles are created for all possible aspect and depression angles. It was mentioned in subsection 3.2 that the range location and

intensity of the major scatterers appear to be stable over a range of aspect and depression angles. Given the scenario in which aspect angles range from 0 to 360 degrees and depression angles range from 0 to 44 degrees, there would typically be about 880 distinguishable orientations for a SAR image of a ship, assuming an angular increment of 18 degrees in aspect and 1 degree in depression. For a 100 ship library, there would be 88,000 different range profiles that can be created. For each of these range profiles, values are extracted for the range extent, and the number, level and location of peaks. Values for the following image features are known exactly and do not have to be estimated: ship length; aspect and depression angles; presence and location of a rotating antenna; and location of the ship bow.

The storage requirements for this library would be roughly 10.6 Mbytes. This number assumes that each range profile contains ten peaks (i.e. storage for 21 real numbers broken down as follows: the number of peaks, the level of each peak, and the range location of each peak relative to the center of the range profile), and that one real number is required to represent each of the following additional pieces of information: the true length of the ship; the range extent of the range profile; the location of the bow; the center of the range of depression angles; the center of the range of aspect angles; and the location of an antenna. Also, one logical variable is needed to store whether an antenna is present or not. Finally, one 10 byte character string is required to store the class of the ship. Based on IEEE 754 standard, one real number requires 4 bytes of memory. This gives a total of 27 real numbers, one logical variable (the logical variable requires only 2 bytes for storage), and a 10 byte character string. The memory requirement is thereby 120 bytes for each range profile, for a total memory requirement of about 10.6 Mbytes.

3.3.2 Classification of Input SAR Images

The first step of the classification process used by the CFC involves creating a range profile of the input SAR image. The pixel resolution of the profile is interpolated so that it matches the resolution of the range profiles in the library. The image is then amplitude normalized as is done for the library profile images. Next, the image features are extracted from the profile, SAR image or radar data, depending upon the feature. Finally, this set of features is compared to the library described above.

Since bounds on the aspect angle of the ship in the image are computed, this limits the search to a small fraction of the library. In addition, bounds on the true ship length are used to further reduce the list of potential classes of ships. Using this reduced sized library, a comparison of range extents is made. Even though the range to the target and height of the SAR are both known, the depression angle is not known precisely since the ship is usually experiencing some unknown pitch or roll, which alters the effective depression angle.

Since the range extent could vary because of various uncontrolled imaging effects, a tolerance on the range extent comparison must be used. This tolerance is empirically

determined to be a percentage of the input image's range extent. All ships that match this range extent, to within the specified tolerance, are carried on to the next comparison stage in which a search is made for a rotating antenna.

If a rotating antenna is detected in the input SAR image, then all ships which do not have an antenna are removed from further consideration. If a rotating antenna is not detected, then nothing is done.

Next, the number of peaks are compared. This comparison also requires a tolerance, which is empirically determined. All ships which match this number, to within the tolerance, are passed to the final comparison stage in which the locations of the peaks are matched.

One method to match peak locations is to compute a similarity measure between the input range profile and a profile from the library. The similarity measure is based upon finding the best match of both peak height and location between profiles. The matching is done to within certain tolerances, which are empirically determined. Once the best match is found, a correlation is computed. Only those profiles which produce a correlation value above an empirically determined threshold are considered to represent the candidate ships.

When matching two profiles, a point of reference is needed between the profiles. If a rotating antenna exists in the input SAR image, then its location can be used as a reference point for matching to the library images. If no rotating antenna is present, then the range centroids of both profiles are matched, and the best alignment of the two range profiles is found over a range of possible offset values.

The candidate ships found by the CFC are passed on to the Radar Operator for a more detailed analysis.

4.0 CONCLUDING REMARKS

At this time, all of the CFC components, except for the estimation of the bounds of the ship aspect angle and length, are defined and implemented in Fortran. Implementation of the estimation techniques for these two features is expected to be completed by early 1992. Testing of this algorithm has not yet been undertaken because the offline library is still being created. It is anticipated that preliminary results will be available within six months.

It is envisioned that the CFC will lessen the work load of the Radar Operator while performing the ship classification task. If desired, the output from each processing stage of the CFC can be provided to the Operator to verify the decisions made by the CFC. The Operator would most likely be best employed in analyzing the fine details of the list of candidate ships output from the CFC. From this list, the Operator can then more easily choose the single most appropriate ship class.

Since the CFC uses only coarse features to classify, it is anticipated that no single class of ship will be output, but more likely a list of classes. From an initial library of 100 classes of ships, perhaps only ten or less will be considered as candidate classes. This certainly will result in both a speed up in classification and an improved classification accuracy, both achievements being the original design goals for the CFC.

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Synthetic Aperture Radar (SAR) systems have made possible the generation of radar images of ships with high enough resolution to allow numerous targets or scatterers to be visible. With the availability of numerous scatterers in one radar image, it is theoretically possible to identify the class of a ship. The SAR image of a ship is a function of the location of scatterers, the SAR system frequency, the radar-to-ship viewing angle, the amount and type of sea-induced ship motion, and the length of the aperture. Because of the dependence on these variables, the number of images representing any one ship is large. It is the job of a Radar Operator to study and understand the abundance of radar images that can be encountered, and attempt to make the correct classification. Fast classification response times are required, however, since these images would normally be acquired in a real-time scenario. As a result of the large number of images and the fast classification response required, some form of computer-based aid for the operator is justified.

A Syntactic Pattern Recognition Algorithm (called the Coarse Feature Classifier (CFC)) has been developed to aid the Radar Operator in performing the task of classifying SAR images of ships. By having the algorithm perform some of the tasks that the operator normally performs, one obtains the potential benefits of improved accuracy and speed of classification, and reduced operator fatigue. The algorithm extracts numerous features from the input SAR image which are then compared to a library of similar features in order to select the ship(s) from the library which best resembles the input ship image. The details of the operation of the CFC are discussed in this report.

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